from underground aquifers or by building an undersea pipeline from the mainland.

There had been a long-held belief that secure sources of potable groundwater could not be found at Rottnest. This was because in 1911-12 an artesian bore drilled on the island had recovered nothing but salt water, and shallow bores and wells around the Thomson Bay settlement yielded only brackish to very saline water. The Geological Survey's re-evaluation of the groundwater prospects in 1976 showed that the chances of finding potable artesian water were almost nil, but that the most prospective part of the island for shallow groundwater, situated below the high ground west and south of the salt lakes, had never been tested. It was suggested that these areas could yield significant volumes of domestic-quality groundwater, and that accordingly they should be drilled as soon as possible (Playford 1976). The prediction was proved correct; two lenses of fresh (less than 1 000 mg/L) to brackish (1 000 to 2 000 mg/L) water were defined in these areas (Fig. 4). The area west of Wadjemup Hill contained sufficient reserves of potable water in a lens up to 10 m thick in the Tamala Limestone to be developed for use in the settlements (Playford and Leech 1977). The necessary bores and a pipeline were completed within a few months, and production began in October 1976. Since then exploitation of the groundwater lens has proceeded without major problems, and it is estimated that abstraction in each year has averaged only 9% of the annual recharge from rainfall.

Supplies from this source together with those from existing sealed catchments should be sufficient to meet the essential potable water needs of the island for many years. The other lens, in the Oliver Hill area, contains mainly brackish water, but it has potential for development to improve the second-class water system (for ablution and sanitary purposes), which at present is supplied by saline wells in the settlement areas.

## References


Churchill, D. M. (1959).—Late Quaternary eustatic changes in the Swan River district. *Jour. Roy. Soc. W.A.*, **42**: 53-55.

Deevey, E. S., Gralenski, L. J., and Hoffren, V. (1959).—Yale natural radio-carbon measurements IV. *Radiocarbon*, **1**: 144-172.

Fairbridge, R. W. (1953.—*Australian stratigraphy*. Univ. of W.A. Text Books Board, Nedlands.

Fairbridge, R. W. (1958).—Dating the latest movements of the Quaternary sea level. *Trans. New York Acad. Sci.* ser. 2, **20**: 471-482.

Fairbridge, R. W. (1961).—Eustatic changes in sea level, in *Physics and chemistry of the earth*, **4**: 99-185, Pergamon, London.

Glenister, B. F., Hassell, C. W., and Kneebone, E. W. S. (1959).—Geology of Rottnest Island. *J. Roy. Soc. W. Aust.*, **42**: 69-70.

Hassell, C. W., and Kneboone, E. S. W. (1960).—*The geology of Rottnest Island*. Unpublished B.Sc. Honours thesis Univ. of W.A. Dept. Geology.

Kendrick, G. W. (1977).—Fossils from the Herschell Limestone. *Geol. Surv. W.A.* Rept **6**: 87-98.

Playford, P. E. (1976).—Rottnest Island: geology and groundwater potential. *Geol. Surv. W.A.* Record 1976/7.

Playford, P. E., and Leech, R. E. J. (1977).—Geology and hydrology of Rottnest Island. *Geol. Surv. W.A.* Rept **6**: 1-86.

Playford, P. E., Cockbain, A. E., and Low, G. H. (1976).—Geology of the Perth Basin, Western Australia. *Geol. Surv. W.A.* Bull. **124**: 311 p.

Tamers, M. A., Pearson, F. J., and Davis, E. M. (1964).—University of Texas radiocarbon dates. *Radiocarbon*, **6**: 138-159.

Teichert, C. (1950).—Late Quaternary changes of sea level at Rottnest Island, Western Australia. *Proc. Roy. Soc. Victoria*, **59**: 63-79.

Veeh, H. H., (1966).—$Th^{230}/U^{238}$ and $U^{234}/U^{238}$ ages of Pleistocene high sea level stand. *Jour. Geophys. Res.* **71**: 33-79-3386.


# Salmonella on Rottnest Island: Implications for public health and wildlife management


by J. B. Iveson and R. P. Hart

State Health Laboratory Services, Queen Elizabeth II Medical Centre, and Department of Zoology, University of Western Australia



### Abstract

Salmonella infections of 40 serotypes have been studied in humans, a wild marsupial (the quokka, *Setonix brachyurus*), birds and the environment on Rottnest Island (W. Australia). The vegetation of the island is very disturbed and during the hot and dry summer the quokkas suffer starvation. Up to 100% of the quokkas are infected throughout the summer (median rate of excretion $10^{3.5}$/g of faeces) although there is no evidence of disease. There is widespread environmental contamination and consequent infection of birds and humans. The situation has been studied in detail in relation to public health and wildlife management.

## A) Public health aspects

### Introduction

The epidemiology of non-typhoidal salmonellosis and the emergence of the disease as an international public health and veterinary problem is inexorably linked with ecological changes affecting the behaviour of humans, domesticated animals and wildlife.

Fauna populations located on small islands close to densely-populated areas are particularly vulnerable to environmental changes, and public health problems may arise when man-induced changes in habitat and behaviour involve wildlife more closely in the epidemiology of human infections.

The discovery in 1972 of a major reservoir of salmonella infections in the quokka population (Iveson and Bradshaw 1973) was a finding of considerable public health and ecological significance. The popularity of the island as a recreational centre was rapidly increasing, and it was evident that additional bacteriological monitoring procedures covering water supplies, waste disposal facilities, effluents and island fauna, were necessary precautions in order to maintain health standards and minimise risks of infection to the public.

### Salmonella infections

Salmonellosis in humans is usually acquired after ingestion of the pathogen in contaminated food or water. Close association with infected patients, carrier animals, contaminated soil or droppings exposes humans more directly to risks of infection. Symptoms of acute gastroenteritis usually commence 18-24 hours after exposure to infection, diarrhoea continues for a few days, but may continue for protracted periods and develop into a lengthy carrier state. Septicaemia, meningitis and other serious clinical manifestations may also occur as rare complications. The first laboratory confirmed human salmonella case traced to Rottnest Island occurred in April 1972 when a 14-month old infant developed symptoms of acute enteritis during an island vacation. *Salmonella javiana*, a serotype which had not previously been isolated from humans in Western Australia, was isolated on two occasions from the child's faeces.

A single isolation of *Salmonella javiana* had been recorded previously from a dugite *(Pseudonaja affinis)* captured on the island. The child became ill after playing in sand surrounding the holiday accommodation, which was copiously littered with quokka *(Setonix brachyurus)* and silver gull *(Larus novaehollandiae)* droppings. Several quokkas were domiciled under the hut and the parents had observed the child playing with fresh quokka droppings which were occasionally transferred from hand to mouth.

Subsequent investigations at the holiday site (Iveson and Bradshaw 1973), revealed that quokkas and their droppings were heavily infected with a wide range of serotypes, including *Salmonella javiana*. The extent of infections in quokkas was remarkable and in these first studies a total of 100 isolations comprising 92 *Salmonella* and 8 *Arizona* serotypes were recorded from 62 (71%) of 87 adult quokkas tested. Multiple infections were common and up to four serotypes were detected in individual quokkas. Since April 1972, a total of 22 laboratory-confirmed salmonella infections in humans has been traced directly to Rottnest Island. Of these, 17 infections have occurred in vacationers and 4 in residents. A further *Salmonella javiana* case occurred in a contact hospitalised on the mainland. To put these data in context : 3 582 isolations were reported on the mainland over the same period.

### Water and sewage

Coliforms and occasionally salmonella have been isolated from the water supply usually in the wake of chlorination problems or post-chlorination contamination by wildlife gaining access to tanks. A total of 24 serotypes and 130 salmonella isolations have been recorded from water storage tanks or wells since monitoring was intensified in 1972. The major serotypes comprised *S. adelaide* 16, *S. anatum 12*, S. *chester 10*, S. *javiana 10*, S. *muenchen 26*, *S. newington* 16, *S. wandsbek* 11, and *S. waycross* 8.

The well waters piped to the sink of the Rottnest Biological Research Station kitchen were found, prior to upgrading, to be contaminated with faecal coliforms, *S. adelaide, S. waycross, S. barhenfeld, S. newington* and *S. muenchen*.

Well waters at the old Riding School were also heavily contaminated and multiple serotypes including *S. javiana* were also isolated from sick horses, and poultry supplied with water from the well.

The tapsites and drainage sumps located in the camping area are foci for people, silver gulls, crows, black swans and quokkas. Salmonella contamination is a constant feature of surface waters, soil and droppings around these sites.

Monitoring of sewage from both mains and coastal outfall sites has identified 19 salmonella sertoypes including *S. javiana*, in a total of 114 isolations.

### Quokkas

Since May 1972 a total of 4 038 quokkas including a small number of recaptured animals has been examined for salmonella and 1 551 (38%) of these were positive. The major isolation are as follows:— *S. muenchen* 484, *S. newington* 291, *S. adelaide*, 239, *S. wandsbek* 125, *S. oranienburg* 93, *S. chester* 84, *S. orientalis* 79, *S. javiana* 76, *S. waycross* 77, *S. typhimurium* 75, *S. rottnest* 38, *S. bahrenfeld* 36 and *Arizona 26:26:25* 39.

Collection sites in this review of isolations have been broadly grouped in to less-disturbed areas in the central and western parts of the island and also the more disturbed eastern areas where the settlements and major recreation areas are situated. A summary of serotypes and isolation totals is presented in Table I.

### Epidemiology of *Salmonella javiana*

The geographical distribution and published evidence indicating the undoubted virulence of *S. javiana* to humans has been reviewed previously (Iveson and Bradshaw 1973). *Salmonella javiana* was first identified on Java (Edwards and Bruner 1942). The serotype is common in quokkas and droppings throughout the settlement area, but has not been isolated to date from the relatively-undisturbed fauna on the West End area of the Island.

The landing on Rottnest Island of Volkersen on March 9th, 1658, after sailing South from Batavia, provided the first of many opportunities for the

**Table 1**

Salmonella isolations from quokkas on Rottnest Island 1972–1982 inclusive

| Salmonella serotypes | Least-disturbed areas | | | | Disturbed areas | | | Totals |
|---|---|---|---|---|---|---|---|---|
| | West End | Central | South & east | Lake site | Tip site | Golf Course | Settlements | |
| *S. adelaide* | 19 | 47 | 21 | 14 | 37 | 48 | 53 | 239 |
| *S. alsterdorf* | .... | .... | .... | 1 | .... | | .... | 1 |
| *S. anatum* | 2 | 3 | 4 | 2 | 1 | 6 | 3 | 21 |
| *S. bahrenfeld* | 1 | 29 | 5 | | .... | .... | 1 | 36 |
| *S. bleadon* | 6 | 1 | .... | .... | .... | .... | .... | 7 |
| *S. blukwa* | 1 | | 1 | .... | .... | .... | .... | 2 |
| *S. bootle* | 3 | 1 | .... | 3 | 1 | .... | 1 | 9 |
| *S. bovis-morbificans* | .... | .... | .... | 1 | 1 | 3 | 2 | 7 |
| *S. bunnik* | .... | 1 | .... | | .... | .... | .... | 1 |
| *S. chester* | 4 | 21 | 5 | 5 | 10 | 27 | 12 | 84 |
| *S. decatur* | | 4 | .... | 1 | .... | 1 | 2 | 8 |
| *S. derby* | .... | .... | .... | 1 | .... | .... | 1 | 2 |
| *S. fremantle* | 5 | .... | .... | .... | .... | 2 | .... | 7 |
| *S. give* | 2 | | .... | .... | .... | .... | .... | 2 |
| *S. infantis* | .... | | | .... | 2 | .... | .... | 2 |
| *S. javiana* | .... | 15 | 7 | 10 | 21 | 12 | 11 | 76 |
| *S. muenchen* | 49 | 213 | 49 | 47 | 50 | 39 | 37 | 484 |
| *S. newington* | 40 | 130 | 22 | 38 | 25 | 28 | 8 | 291 |
| *S. newport* | | | .... | | | 1 | 3 | 4 |
| *S. orianienburg* | 5 | 29 | .... | 3 | 33 | 15 | 8 | 93 |
| *S. orientalis* | 1 | 28 | 11 | 9 | 18 | 9 | 3 | 79 |
| *S. orion* | 2 | 11 | 4 | | 3 | 1 | 5 | 26 |
| *S. potsdam* | .... | .... | .... | 1 | .... | .... | .... | 1 |
| *S. rottnest* | 9 | 9 | 10 | .... | 3 | 7 | .... | 38 |
| *S. saint-paul* | .... | .... | .... | | .... | .... | 1 | 1 |
| *S. singapore* | .... | 1 | 1 | | .... | .... | 1 | 3 |
| *S. typhimurium* | 5 | 18 | 6 | 10 | 16 | 3 | 17 | 75 |
| *S. wandsbek* | 10 | 50 | 7 | 12 | 21 | 17 | 7 | 125 |
| *S. waycross* | 2 | 20 | 2 | 9 | 7 | 19 | 18 | 77 |
| S. 48:d:— | 1 | | .... | .... | .... | .... | .... | 1 |
| A. 9: 26:21 | 1 | 1 | .... | 1 | .... | .... | .... | 3 |
| A. 9: 26:31 | .... | 1 | .... | .... | .... | .... | .... | 1 |
| A. 9: 29:21 | 2 | 1 | .... | .... | .... | .... | 1 | 4 |
| A. 16:23:25 | 3 | 6 | .... | .... | .... | 1 | .... | 10 |
| A. 16:26:25 | .... | .... | .... | .... | 1 | .... | .... | 1 |
| A. 20:29:21 | 1 | 2 | .... | .... | .... | 1 | .... | 4 |
| A. 20:29:25 | 1 | 4 | .... | 1 | .... | .... | .... | 6 |
| A. 26:23:21 | .... | 2 | .... | | .... | .... | .... | 2 |
| A. 26:26:25 | 7 | 18 | 3 | 1 | 2 | 2 | 6 | 39 |
| A. 28:32:28 | .... | | .... | 1 | | .... | | 1 |
| Arizona spp. | .... | 4 | .... | 1 | 1 | .... | 8 | 14 |
| Isolations | 182 | 670 | 160 | 171 | 253 | 242 | 209 | 1 887 |
| Serotypes | 25 | 28 | 27 | 21 | 24 | 20 | 30 | 40 |
| Quokkas | 313 | 912 | 290 | 271 | 674 | 699 | 879 | 4 038 |
| Quokkas +ve | 140 | 511 | 141 | 130 | 234 | 203 | 192 | 1 551 |
| % +ve | 45% | 56% | 49% | 48% | 35% | 29% | 22% | 38% |

unnatural introduction of serotypes from other countries and continents and also a possible source of entry for *S. javiana*, which is absent from terrestrial wildlife and introduced livestock on the W.A. mainland. The exotic strain hypothesis for *S. javiana* is supported by the tracing of the origin of all human *S. javiana* cases occurring in Western Australia either to Rottnest Island or South-East Asia including Bali and Java Islands. The prevalence of *S. javiana* and *S. typhimurium* phage 202 in quokkas and humans on Rottnest Island and their absence from foodchains on the mainland, have led to routine precautionary quarantine procedures, for all quokkas and other fauna removed from the island (Iveson and Bradshaw 1977).

### Reptiles and frogs

Previous studies in Western Australia (Iveson, Bamford and Mackay-Scollay 1969; Iveson 1971, 1977), have established that reptiles throughout Western Australia are natural carriers of numerous salmonella serotypes. Furthermore reptiles examined from the disturbed Rottnest and Carnac Island habitats carry many indigenous infections as well as exotic serotypes common to the introduced urban and agricultural ecosystems on the mainland. The predominance of *S. derby* for example in king skinks (*Egernia kingii*), tiger snakes (*Notechis scutatus*) sea lions (*Neophoca cinerea*) and silver gulls (*Larus novaehollandiae*) on Carnac Island, which is exposed directly through seagull vectors to *S. derby* and other exotic strains in mainland abattoir and sewage effluents, is a good example of exotic infections being transmitted to wildlife as a result of human disturbance (Iveson 1979). A total of 30 salmonella serotypes and 102 isolations have been recorded from reptiles examined on Rottnest Island. Infection rates have averaged 66%, and in one lizard (*Tiliqua rugosa*) 9 serotypes were detected during multiple sampling. Salmonella have been isolated from reptiles frequenting picnic areas, campsites, army barracks, sewerage facilities, water catchment areas and



24584—(3)

**Table 2**

Salmonella isolations from reptiles, birds and domestic animals on Rottnest Island 1972 1982 (inclusive)

(Figures in brackets are isolations from bird droppings)

| Salmonella serotypes | Lizards | Snakes | Birds | Domestic animals | Totals |
|---|---|---|---|---|---|
| *S. adelaide* | 5 | .... | 1 (8) | 22 | 36 |
| *S. anatum* | .. | .... | .... (3) | 17 | 20 |
| *S. alsterdorf* | 4 | .... | .... | .... | 4 |
| *S. bahrenfeld* | 2 | 1 | .... | .... | 3 |
| *S. blukwa* | 3 | .... | .... | .... | 3 |
| *S. bootle* | 3 | .... | .... | .... | 3 |
| *S. bovis-morbificans* | .... | .... | .... (1) | .... | 1 |
| *S. bunnik* | 5 | 2 | .... | .... | 7 |
| *S. chester* | 5 | ... | 1 (2) | 15 | 23 |
| *S. decatur* | 2 | .... | 1 | 1 | 4 |
| *S. derby* | .... | .... | 1 | .... | 1 |
| *S. give* | 1 | .... | .... | .... | 1 |
| *S. havana* | .. | .... | 1 | .... | 1 |
| *S. houten* | .... | 2 | .... | 1 | 3 |
| *S. javiana* | .... | 1 | .... (2) | 15 | 18 |
| *S. muenchen* | 3 | 3 | 1 (8) | 12 | 27 |
| *S. newington* | 4 | 1 | 1 (2) | 32 | 40 |
| *S. oranienburg* | 2 | .... | .... | 3 | 5 |
| *S. orientalis* | 3 | .... | .... (1) | 8 | 12 |
| *S. orion* | 2 | .... | .... | 2 | 4 |
| *S. rottnest* | 2 | 1 | .... | .... | 3 |
| *S. typhimurium* | 1 | 1 | 2 (6) | 8 | 18 |
| *S. wandsbek* | 5 | | 1 (1) | 9 | 16 |
| *S. waycross* | 2 | .... | .... | 10 | 12 |
| *S.* 53:d:z42 | 2 | .... | .... | .... | 2 |
| A. 16:23:25 | .... | 6 | .... | .... | 6 |
| A. 20:29:25 | .... | 2 | .... | .... | 2 |
| A. 26:23:21 | .... | 1 | .... | .... | 1 |
| A. 26:26:25 | 4 | 4 | .... (1) | .... | 9 |
| A. 28:32:28 | 1 | 6 | .... (1) | .... | 8 |
| A. 29:26:28 | .. | 1 | .... | .... | 1 |
| A. 29:29:25 | 2 | 2 | .... | .... | 4 |
| A. 1, 33:23:21 | | 2 | .... | .... | 2 |
| A 26:23·25 | .... | 2 | .... | .... | 2 |
| Isolations | 63 | 38 | 10 (36) | 155 | 302 |
| Animals | 58 | 18 | 417 | 45 | 538 |
| Animals +ve | 36 | 14 | 10 | 40 | 100 |

the inside of water storage tanks. Salmonella serotypes and isolation totals from reptiles, birds and domesticated animals are detailed in Table 2. *S. decatur* was isolated from a frog (*Litoria moorei*) sampled in the settlement area.

### Birds

Salmonella carrier rates among birds are low, averaging 2.4%. The majority of isolations have been from cloacal swabs or fresh droppings collected from silver gulls, and 8% of 105 gulls examined yielded salmonella comprising 15 serotypes. Isolations were also recorded from mountain duck (*Tadorna tadornoides*), black swans (*Cygnus atratus*), and welcome swallows (*Hirundo neoxena*). No salmonella were detected in wedge-tailed shearwaters (*Puffinus pacificus*), kestrels (*Falco cenchroides*), ospreys (*Pandeon holiaetus*), crested terns (*Sterna bergeii*) or droppings from introduced senegal doves (*Streptopelia senegalensis*), pheasants (*Phasianus colchicus*), and peacocks (*Pavo cristatus*).

Swallows and silver gulls were implicated in water storage contamination problems. Silver gulls were also present in large numbers at open air drinking and eating venues.

### Domestic animals

Multiple recurring salmonella infections including *S. javiana* were detected in horses and a donkey used for public hire. It was evident that equines made a significant contribution to contamination problems on the island and were a potential source of infection to the public. Horse dung was also detected in swallow nests inside water storage tanks (Iveson and Bradshaw 1977).

### Discussion

The epidemiological studies and on-going monitoring programmes, have revealed both active and latent reservoirs of infection on the island with foci in quokkas, birds, reptiles and domesticated animals. The majority of human cases has been caused by *S. javiana* which is not found on the mainland. Sewage monitoring has also provided evidence of latent human infections.

Significant contamination of water storage facilities, the settlement environment and occasionally waters used for bathing and fishing have been documented.

However, regular maintenance and upgrading of water and sewage facilities have maintained public health standards and reduced high risks of exposure to infection.

Since 1972 a small number of salmonella cases has been traced to contact with infected animals or their droppings, however the total of 22 cases recorded to date represents only 0.6% of the 3 582 cases which have occurred over the corresponding period in the Perth Metropolitan Region. All patients have made an uneventful recovery, however the public health importance of the overall findings emphasises the continuing need for adequate preventative measures including regular bacteriological monitoring of waters, animals and environment particularly at peak summer vacation periods.

Increased public usage of the island facilities, and further increases in levels of interaction between humans and animals will require careful management if problems are to be avoided particularly in settlement areas (Iveson and Bradshaw 1977). Quokkas and scavenging birds will continue to be attracted to these areas as long as access to supplementary food and water is freely available. Furthermore public feeding practices interfere with the natural processes of population regulation and amplifies naturally occurring cycles of infection. Combined public health and wildlife management strategies are essential ingredients in preventing further involvement of wildlife in the epidemiology of human infections.

## B) Salmonella in the Rottnest Quokka—a wildlife management problem

### Introduction

The first record of a *Salmonella* from a quokka (*Setonix brachyurus*) was of *S. newport* made from the pouch of a captive Rottnest animal (Yadav, Stanley and Waring 1972). However Iveson and Bradshaw (1973) first drew attention to the abundance of enteric infections in Rottnest quokkas.

Recent studies have focused attention on the opportunistic nature of the salmonella and it is now known that a wide range of environmental stresses can convert a latent and harmless infection into an active infection and possibly a disease state. These stresses include food and water deprivation, handling stress, disease and environmental discomfort (Hart 1980). The vast majority of infections are now believed to be non-disease states. This dependence on host-related factors suggests that the salmonella may be useful indicators of such stresses. The Rottnest quokka appeared to provide a convenient case study of this phenomenon, since it is known to suffer a severe seasonal stress (Main, Shield and Waring 1959).

### The patterns of infection

The frequency of salmonella infections was found to be markedly seasonal (Hart 1980). In most areas of the island the infection rate (percentage of animals positive by rectal swab) was 0-30% in the winter (June-Oct) and 70-100% in the summer (Nov-May). The change-over between these levels was very abrupt and probably occurred in a matter of a few weeks. In several areas on the island this pattern did not occur. In the settlement (and surrounding areas) and at the tip site the infection rate was always low (0-30%). These patterns were related to the well-being of the animals by using the body weight-based Condition Index of Bakker and Main (1980). In all cases where there was a seasonal cycle of infection rate there was also a marked seasonal cycle of condition. The animals reached maximum weight as late as December, declined slowly until about February and then showed a dramatic decline until May. During the winter they showed a slow recovery which accelerated in the spring. Conversely in the areas where there was no change in infection rate there was no change in condition and the animals remained in good condition in all seasons.

### Relationship between infections and nutrition

Although it was clear that the salmonella infections and poor condition were related in that both or neither occurred in any one population it was also clear that poor condition was not the cause of the infections since the infections precede this in time. The relationship of the infections to nutrition was examined firstly by quantitative study of the timing and course of infections over the summer period and secondly by feeding animals in the field (Hart 1980).

Using animals sacrificed over the critical spring to summer period it was found that up to $10^3$ salmonella cells per ml of stomach fluid could be recovered as early as the end of October. Furthermore there was a significant correlation between the numbers of *Salmonella* cells in the stomach and in the faeces. By the end of summer virtually all animals were excreting Salmonella at a rate of greater than $10^3$ *Salmonella* cells per gram of faeces. In the settlement area the rate of faecal excretion of salmonella showed only a small rise in late April.

In the second study a population was divided in two and one half received a complete food and water supplement. This was done in the field so that the animals were otherwise exposed to all normal stresses, and the feeding commenced just before the critical spring-summer change. The animals which received the food supplement did not show the abrupt proliferation of salmonella infections until immediately after the food was withdrawn five weeks later. After another three weeks the test and control groups were indistinguishable. Again the animals did not reach their maximum weight until as late as December, **after** the experiment had ended.

In a further analysis of the quantitative results (Hart 1980) it was found that there was a significant correlation between the incidence of infections and the weather. The median rate of faecal excretion began to rise as soon as the rains ended (the temperature is of course strongly and inversely correlated with rainfall) and fell abruptly with the return of the rains in autumn.

### Salmonella in the Rottnest environment

Hart, Iveson and Bradshaw (unpub.) studied the behaviour of some 40 serotypes of *Salmonella* which occur on Rottnest. By examining the spatial and temporal distribution of 1 754 isolations from 3 751 quokkas it was found that there were significant variations in the distribution of some serotypes in some locations. In examining two of these locations, evidence was found that the variations were due to amplification of a serotype in another host. These were *S. javiana* in the welcome swallow *(Hirundo neoxena)* and *S. typhimurium* phage-type 202 in the silver gull *(Larus novaehollandiae,)* both in the settlement area.

A major object of this study was to document differences between the group of native serotypes and the introduced serotypes described by Iveson (1977). It was found that these groups did not behave coherently and each serotype had to be examined separately. The only apparent distinction was that relatively more of the rare native serotypes occurred on West End (the most isolated segment of the island) and relatively more of the rare introduced serotypes in the settlement. These differences show the failure of many introduced serotypes to invade West End, and document the presence in the settlement of recently-arrived serotypes which have not yet dispersed. There is thus strong evidence that new serotypes are still becoming established on Rottnest.

An important finding of this study was that the range of serotypes present on Rottnest showed marked differences to that of the adjacent mainland, and there appears to be little interchange.

### Discussion

Hart (1980) suggested that the *Salmonella* are able to proliferate in the Rottnest quokka because the normally hostile stomach contents are altered as the diet of the animals changes abruptly at the end and beginning of the winter rains. The most likely mechanism for this is a drop in volatile fatty acid production which would raise the pH. In this way the *Salmonella* infections precede the effects of the subsequent starvation. Although infections are established in this way there is no necessary consequence of a disease state. The levels of *Salmonella* excretion reported by Hart (1980) are too low to represent disease. This supports the finding of Shield (1959) that disease does not appear to be a factor in the summer decline of the animals. The animals in the settlement and tip site are able to avoid this situation by receiving a food supplement in the form of hand-outs and garbage.

Despite some three decades of work there is still no general agreement on the precise nature of the summer decline of the Rottnest quokka (reviewed by Miller & Bradshaw 1979) however the *Salmonella* appear to be an indicator of the presence of environmental stress, and more particularly of the precise beginning and end of the period over which the stress operates. The present difficulties of the Rottnest quokka are believed to be due to recent human-related changes in the vegetation (mostly by burning and overgrazing) which have altered the vegetation from a dense woodland and shrubland to an open steppe dominated by species less palatable to the quokka and annual weeds (Storr 1963, Pen and Green, this volume). However the results of a study of quokkas living on Bald Island (Hart 1980) suggest that the Rottnest quokka may already have suffered a severe summer starvation before European settlement. Before this time only native serotypes could have been involved in the annual proliferation.

At present the annual proliferation of *Salmonella* in the Rottnest quokka represents a significant reservoir of infection and this situation results from the degraded environment afforded the Rottnest quokka. The annual proliferation will go on until seasonal starvation is removed as the dominant feature of the biology of the Rottnest quokka. The feeding experiment described by Hart (1980) suggests that this could be achieved, by restoring the vegetation and controlling the population so that suitable forage was available. A more difficult problem is the transfer of serotypes between Rottnest and the mainland. New introduced serotypes on Rottnest can only exacerbate the problems, while the transfer of *S. javiana* to the mainland could have serious consequences (see Iveson and Bradshaw 1973).

Hart (1980) has discussed the more general application of *Salmonella* infections as indicators of environmental stress on wild animals. He has proposed that while any large concentration of *salmonella* suggests such stress, the presence of introduced serotypes indicates either heavy input from another source (as has been described by Iveson 1979, for Carnac Island by silver gulls) or that the host has been rendered susceptible to infection and has amplified a small input (as has happened on Rottnest Island and particularly Bald Island). These ideas may find application in the management of natural ecosystems.

### References


Bakker, H. R. and Main, A. R. (1980).—Condition, body composition and total body water estimation in the quokka, *Setonix brachyurus* (Macropodidae). *Aust. J. Zool.*, **28**: 395-406.

Edwards, P. R. and Bruner, D. W. (1942).—Two new salmonella types with related specific antigens. *Jour. Immunol.*, **44**: 319.

Hart, R. P. (1980).—Ecology of the salmonella in a wild marsupial, the quokka *Setonix brackyurus*. Ph.D. Thesis, Zoology Department, University of W.A.

Hart, R. P., Iveson, J. B., Bradshaw, S. D. and Speed, T. P. (1983).—A study of isolation procedures for multiple infections of Salmonella and Arizona in a wild marsupial, the quokka *Setonix brachyurus*. *Jour. Appl. Bact.*, **53**: (in press).

Iveson, J. B. (1971).—Strontium chloride B, and E. E. enrichment broth media for the isolation of Salmonella, Arizona and Edwardsiella from tiger snakes. *Jour. Hyg. Cambridge*, **69**: 323-330.

Iveson, J. B. (1977).—Salmonella infections in wildlife in Western Australia. A natural barometer of environmental health. Proceedings, *Aust. Inst. of Heath Surveyor, Quart.*, **3**: 5.

Iveson, J. B. (1979a).—*Salmonella* and *E. coli* in the Owen Anchorage Cockburn Sound Environment. Public Health Depart. and Cockburn Sound Study Team Report, June 1979.

Iveson, J. B. (1979b).—Salmonella infections in silver gulls in Western Australia. *W.A. Health Surv. Quart.*, **3**: 5-14.

Iveson, J. B. and Bradshaw, S. D. (1973).—*Salmonella javiana* infection in an infant associated with a marsupial, the quokka *Setonix brachyurus*, in Western Australia. *J. Hyg. Cambridge* **71**: 423-432.

Iveson, J. B., Mackay-Scollay, E. M. and Bamford V. W. (1969).—*Salmonella* and *Arizona* in reptiles and man in Western Australia. *Jour. Hyg. Cambridge*, **67**: 135-145.

Main, A. R., Shield, J. W. and Waring, H. (1959).—Recent studies on marsupial ecology. In: *Biogeography and Ecology in Australia*, A. Keast, R. L. Crocker and C. S. Christian (eds.), 315-331, Uitgevery, Dr. W. Junk, Den Haag.

Miller, T. and Bradshaw, S. D. (1979).—Adrenocortical function in a field population of a macropodid marsupial, *Setonix brachyurus*. *J. Endocrinol.*, **82**: 159-170.

Storr, G. M. (1963).—Some factors inducing change in the vegetation of Rottnest Island. *W.A. Nat.*, **9**: 15-22.

Yadav, M., Stanley, N. F. and Waring, H. (1972).—The microbial flora of the gut of the pouch-young and the pouch of a marsupial, *Setonix brachyurus*. *J. Gen. Microbiol.*, **70**: 437-442.


# Botanical exploration and vegetational changes on Rottnest Island


by L. J. Pen and J. W. Green

30 Fitzroy Street, Queens Park, W.A. 6107.
Western Australian Herbarium, Department of Agriculture, W.A.


### Abstract


The former, extensive cover of low closed forest and closed scrub, characterised by *Callitris preissii, Melaleuca lanceolata* and species of *Acacia*, has declined in area from perhaps 1 000 ha in 1919 to less than 150 ha today, and has largely been replaced by low shrubland dominated by *Acanthocarpus preissii*. These changes, which have not been quantitatively documented, appear to be related to wood-cutting, fire, coastal erosion and grazing by the native marsupial *Setonix brachyurus* (quokka). There is fossil evidence of the prehistoric occurrence of *Eucalyptus gomphocephala* (tuart) woodland.